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Application of CAD and SLA Method in Dental Prosthesis

Shruti S. Bammani [a, 1], Pranav R. Birajdar [b, 1], Shriniwas S Metan [c, 1]
[1] Dept. of Mechanical Engineering, Nagesh Karajagi Orchid College of Engineering and Technology
Solapur, Maharashtra, India.
[a]shruti.bammani@gmail.com, [b]prnvbirajdar@gmail.com, [c]metana@rediffmail.com

Abstract—**Placement of dental implants requires precise planning that accounts for anatomic limitations and restorative goals. Diagnosis can be made with the assistance of computerized tomographic scanning, but transfer of planning to the surgical field is limited. Precise implant placement no longer relies upon so called mental-navigation but rather can be computer guided, based on a three dimensional prosthetically directed plan. Recently, novel CAD/CAM techniques such as stereolithographic rapid prototyping have been developed to build surgical guides in an attempt to improve precision of implant placement. The purpose of this paper is to discuss the use of scanning equipments to transfer clinically relevant prosthetic information which can be used for fabrication of stereolithographic medical models and surgical guides. The proposed method provides solid evidence that computer-aided design and manufacturing technologies may become a new avenue for custom-made dental implants design, analysis, and production in the 21st century.**

Index Terms—**Rapid Prototyping (RP), Stereolithography (SLA), Dental Prosthesis, Dental Implants, Surgical Guides.**

I. Introduction

The development of CAD/CAM is based around three elements, namely: (1) data acquisition, (2) data processing and (3) manufacturing. The exponential increase in power of computers has resulted in major advances in all of these areas. This is particularly exemplified by the recent introduction of various modeling softwares, analysis packages and the novel rapid prototyping techniques.

Rapid Prototyping (RP) is an additive processes that fabricates parts layer-by-layer also known as Layer Manufacturing (LM). They are capable of creating parts with small internal cavities and complex geometries. The process for RP and manufacturing basically consists of three steps: form the cross sections of the object to be manufactured, lay the cross sections layer by layer, and combine the layers [1].

Dental prosthesis fabrication including coping, crown, bridge and fixture, greatly depends on skills of dentists and technicians as it involves much handwork by them. The fabrication of dental prosthesis is also a problem, because practical dental restorations often include freeform surfaces. Moreover, bridges and implant structures tend to have features such as overhangs, undercuts, sharp corners etc.

Since the early 1990s, the medical world has embraced the application of the medical modeling of 3D data to assist in the diagnosis, surgical planning and treatment of complex medical conditions[2], [3]. Application of this technology is now finding its way into implant dentistry [4]. The tremendous increase in the demand of dental implants has fuelled a rapid expansion of the market. Presently, general dentists and multiple specialists offer implants as a solution to partial and complete edentulism (Fig 4).The field is evolving and expanding, from surgical techniques to types of restorations available. Whereas early implant restorations were primarily indicated for rehabilitation of function, increasing consideration is being placed on esthetics in modern implant dentistry.

A. Literature Review

For 20 years, exciting new developments in dental materials and computer technology have led to the success of contemporary dental computer-aided design /computer-aided manufacturing technology [5].

Fuster-Torres M.A. in his study used CAD/CAM systems in implant dentistry, especially emphasizing implant abutments and surgical templates manufacturing. He published this in English at Medline and Scopus databases, introducing “dental CAD/CAM”, “implants abutments” and “surgical guide CAD/CAM” [6].

Cranin et al compared direct bone impression techniques to CAD/CAM-generated models for subperiosteal fabrication and found variations in accuracy [7]. McAllister suggested that stereolithography offered a higher degree of build accuracy and repeatability for subperiosteal implant manufacture [8]. Webb reviewed the use of the RP technique in the medical sector, concluding that the use of RP models was beneficial in terms of measurement and diagnostic accuracy [9].

J.P. Kruth in his work explained in detail regarding the Medical and dental applications. He stressed the advantage of the evolution by using Selective Laser Sintering (SLS) / Selective Laser Melting (SLM), not only for plastic devices like visual anatomical models or one-time surgical guides, but also for functional implants or prostheses with long-term consistency made from a biocompatible metal. Dental applications are very suitable for processing by means of RP&M due to their complex geometries, low volume and strong individualization. The manufacturing of multiple unique parts in a single production run enables mass customization. Moreover, computer controlled production corresponds to the global trend of digitizing the fabrication of medical and dental parts [10].

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B. Stereolithography

Stereolithography (SLA) is the most widely used rapid prototyping technology. It was the first rapid prototyping process, introduced in 1988 by 3D Systems, Inc., based on work by inventor Charles Hull. It is an additive manufacturing process in which a liquid photo curable resin acrylate material is used. SLA uses a highly focused UV laser to trace out successive cross-sections of a three dimensional object in a vat of liquid photosensitive polymer [11], [12].

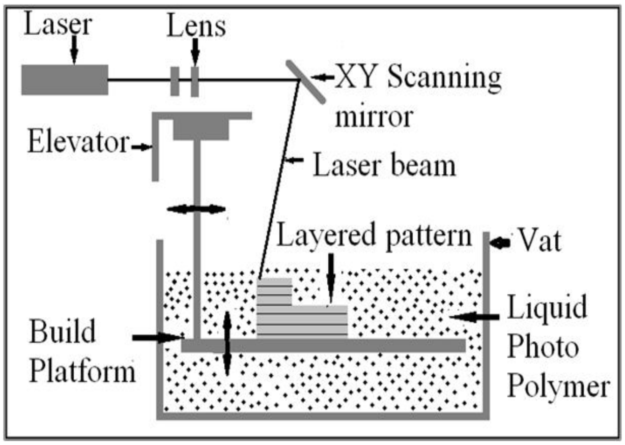

Fig 1: Schematic of SLA process

As the laser traces the layer (Fig 3), the polymer solidifies and the excess areas are left as liquid. When a layer is completed, a leveling blade is moved across the surface to smooth it before depositing the next layer (Fig 1). The platform is lowered by a distance equal to the layer thickness (typically 0.003-0.002 in), and a subsequent layer is formed on top of the previously completed layers. This process of tracing and smoothing is repeated until the build is complete. Once complete, the part is elevated above the vat and drained. In many cases, a final cure is given by placing the part in a UV oven. After the final cure, surfaces are polished, sanded and finished (Fig 2) [13].

C. Need of Digital Dental Prosthesis

Traditionally, implant prosthetic frameworks are fabricated using a wax and cast method. As each step of the process has potential inaccuracies due to polymerization shrinkage or expansion achieving a true passive fit can be difficult. Conventional implant restorations are time and labor intensive, due to the multiple steps in fabrication, such as casting and fitting [14].

Simultaneously, there is an increasing demand for efficient treatment that can be completed in minimal time. Fortunately, technology has kept up with this demand, and the application of CAD/CAM in implant dentistry is a promising solution [15].

A computer aided fabrication process of implants simplifies and accelerates the production turnaround period by using 3D imaging, CAD and RP technology (SLA technique). A detailed description of dental implants using SLA method and future suggestions are also discussed in this paper.

II. DIGITAL DENTISTRY

The following process describes in detail, the modeling, manufacturing and digital surgical techniques used in implant replacement.

A. Geometry Capture and Digital Design

Unlike the traditional method, which needs filling of a tray with impression "goop" that the patient has to bite into his/her mouth until it hardens, the advanced CAD/CAM method includes data capture or scanning using advanced scanners and modelling softwares.

This method uses 3D optical systems for capturing single components anatomy. Some examples are: Interférométrie Moire, laser scan, color coding (such as CEREC and Evolution 4D) [4].

For example, the CEREC certified dentist examines the tooth and determines the appropriate treatment. The first step of the digital procedure is the measurement of the twofold input geometry: firstly the position of the implants in the jawbone of the patient, and secondly the tooth arrangement, approved by the patient. The dentist administers an anesthetic and prepares the tooth for the restoration, removing decayed and weakened tooth tissue. The dentist takes an Optical Impression of teeth which takes approximately two to five minutes.

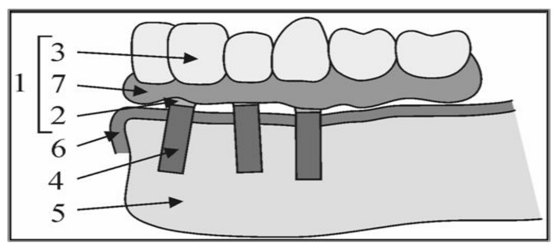

Fig. 2: Scheme of implant-supported prosthesis: 1. Prosthesis, 2. Framework, 3. Teeth, 4. Oral implants, 5. Jawbone, 6. Soft tissue, 7. Artificial gums.

Fig. 3: White light projector pattern during the scanning process by an optical scanner

Based on the scan (Fig. 5.1) a digital 3D teeth model (Fig. 5.2) is designed by fixing measurement errors like gaps, scatters and inverted normals of the surfaces. Each artificial tooth of the final prosthesis needs a support surface on top of the framework, obtained by an offset of the real tooth surface. The different teeth can be identified by means of a curvature analysis (Fig. 5.3). Each separate tooth surface, obtained by cutting the 3D teeth model, is incomplete because

the side surfaces are missing. These side surfaces are needed to compute the offset of the total tooth surfaces. Therefore each incomplete tooth surface is matched with a full point cloud of the corresponding standard tooth (Fig. 5.4). By scanning all teeth at once, a digital library of standard tooth surfaces is available. The support surfaces of the framework are then computed by a defined offset of the completed tooth surfaces (Fig. 5.5), depending on the tooth material (acrylic, composite or porcelain). Conical fitting structures are designed according to these data (Fig. 5.6) and connected to the support surfaces of the teeth (Fig. 5.7). The design of the framework is finished by adding detail features like screw holes and fillets (Fig. 5.8) [16].

Fig. 4: 3D CT reconstruction of a patient with mandibular complete edentulism.

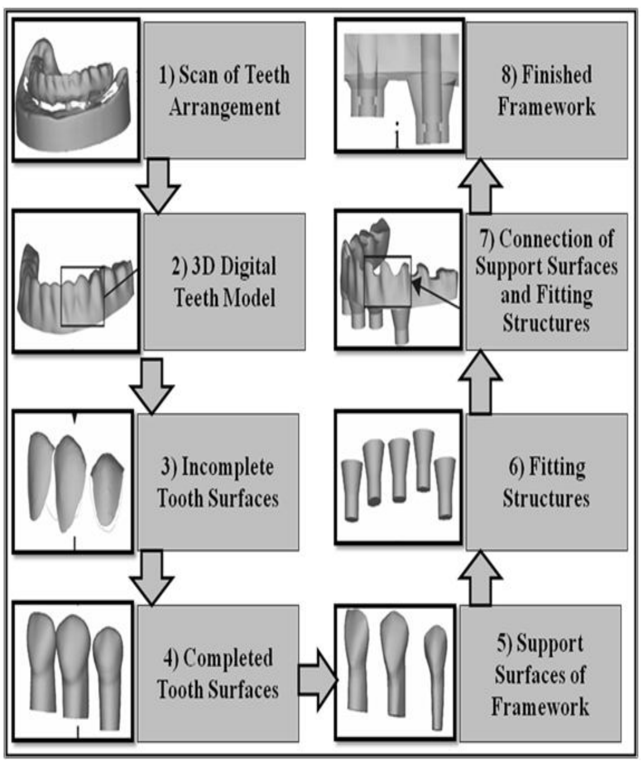

Fig. 5: Digital design strategy

When the design of the framework is complete, the CAD software transforms the virtual model into a specific set of commands. These in turn drive the SLA unit, which fabricates the designed restoration as explained in SLA process [17].

B. Manufacturing of Surgical guides.

Computer-assisted planning and use of CAM surgical guides are used which increases the accuracy of implant placement and improves the outcome of the final restoration. These surgical guides help the surgeon avoid vital structures, and may decrease the length of the surgery.

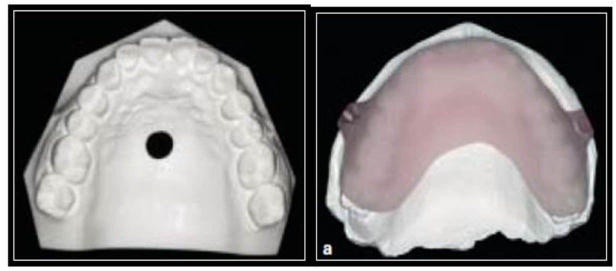

Fig. 6.a: Pretreatment study casts (left). b: Surgical guide fabrication using SLA method (right).

Furthermore, it assures the restorative dentist and dental technician a functional, esthetic, and predictable outcome (Fig. 6a, 6b). Equally important, CAD/CAM design and fabrication of guides improves the patient’s experience with implants and allows the possibility of flapless surgery, which entails less bleeding, less swelling, decreased healing time and post-operative pain [19].

Surgical guides can be produced by three different ways i.e.: conventional, SLA fabricated, and cast fabricated. SLA guides are purely CAD/CAM surgical guides which are generated from Computerized Tomography (CT). CT images were obtained with radiographic templates in place, and implants were placed virtually.The surgical guide was constructed with a rapid prototyping (RP) machine that uses stereolithography, a layer-additive rapid prototyping process based on photo-polymer liquid resins that solidify when exposed to UV light. The RP machine reads the diameter and angulation of the simulated implant, selectively polymerizes the resin around the implant, and forms a cylindrical guide on the replica corresponding to each implant. The technician then removes the supporting resin and uses the cylindrical guide to insert surgical grade stainless steel tubing to serve as the guide tube (Fig. 7.a) [18].

C. CAD/CAM guided surgery

After the diagnostic workout, the first step involves the seating of the surgical guide and the assurance of fit and stability (Fig. 7.b). The guides can stabilized by bone fixation screws. The prime importances of these drilling guides are its security, ergonomic design, accuracy and flexibility [20].

Now with the help of this acrylic resin guide overlying tissues are removed using a trephine allowing bone exposure. This is accomplished through the guide cylinder, which is embedded in the acrylic resin guide. Next the guide cylinders allow the pilot and twist drills for osteotomy site preparation.

The pilot drill is a stepped drill, beginning with a 2.0-mm cutting end and stepping to 3.0mm in diameter for the remaining portion of the twist drill. Physical stops on both the pilot and final twist drills provide for depth control. The same drill length is often is used for all osteotomy sites.

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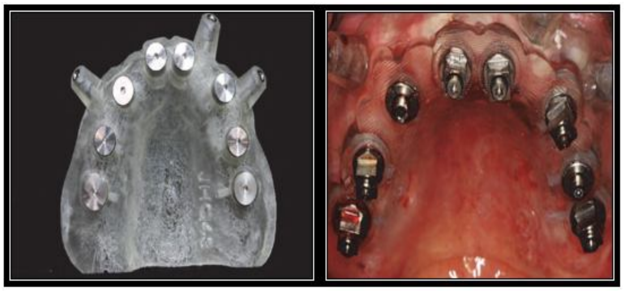

Fig. 7.a: Stereolithographic surgical guides (left)
Fig. 7.b: Fixing guides using pins and cylinders (right)

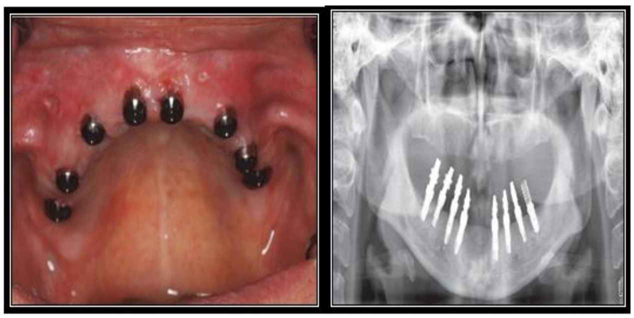

Fig. 8.a: Occlusal view of implants with abutments (left)
Fig. 8.b: Panoramic image of implants. (Right)

Fig. 9.a: Dental prosthesis for immediate loading (left)
Fig. 9.b: Frontal view of completed prosthesis (right)

The second and final twist drill finishes the drilling sequence through the same drilling tube. The final twist drill is 3.15 mm is diameter and is not stepped. Drills of uniform length can be used because of depth is controlled at the time of manufacturing by adjusting the vertical position of the drilling cylinders on the guide.

The drilling cylinders allow the introduction of the specifically designed pilot and twist drills. Only two twist drills are used for osteotomy site preparation in this system: a pilot drill and a final drill. The drill design provides precise tolerance with respect to the drilling tubes, thereby avoiding angulation errors and heat generation.

After the drilling cylinders are removed, implant placement can be completed through the same guide (Fig. 8.a). Implant placement is done using the specially designed implant holders with low tolerance in diameter with respect to the guiding tubes. The physical stop on the implant holders precisely transfers the planned depth and orientation of the implant to the prepared osteotomy site. A CT scan is taken after placing the implants are placed in the edentulous maxilla to ensure the proper fitting of the abutments (Fig. 8.b).

The final step includes loading of the prosthesis (Fig. 9.a, 9.b). In the case of an immediately loaded prosthesis, preparation of the prosthesis can be simplified by completing a major portion of the fabrication presurgically [21], [22].

II. Discussion

There is no doubt that treatment technologies and materials in dentistry have progressively advanced over the past 50 years, especially in the field of restorative dentistry and prosthodontics. There are several directions to apply CAD/CAM systems in dentistry. Among them, introduction of CAD/CAM systems directly into clinics is promising. Patients desire shorter treatment times and early functional recovery for the sake of convenience. CAD/CAM technology applied at the chair-side has the potential to deliver this service. Compact, but high-precision, intraoral measurement systems available for use directly in the mouth at the chair-side must be developed.

Dental device manufacturing has experienced a revolution with layered fabrication techniques reach being able to produce high quality dental prosthesis. The challenge for the dental materials research community is to marry the technology with materials that are suitable for use in dentistry. This can potentially take dental materials research in a totally different direction.

III. Conclusion

A brief description of RP technology is given and a proposed procedure of CAD/CAM technology applied to implant surgery is explained which provides an efficient and fast method to digitally design and manufacture biocompatible metal frameworks for complex dental prostheses using Stereolithography (SLA). CAD/CAM technology has improved predictability of implant surgery with the use of CAD/CAM surgical guides and revolutionized the field of implant dentistry.

SLA medical modeling is accurate and applicable to prosthetically directed implant surgery and allows an efficient and customized production of high resistance, high density implant abutments and surgical guides. Bone-supported surgical drilling guides enable more precise osteotomy preparation with a reduction in surgical equipment and surgical time and also enable standardization of treatment outcomes. It is clear that CAD/CAM technology and SLA production strategy guarantee an accurate fit between the framework and the implants, needed to avoid mechanical or biological failures of the prosthetic system and have transformed all aspects of dentistry, not just implant dentistry.

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